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The environmental impact of mass coronavirus vaccinations: A point of view on huge COVID-19 vaccine waste across the globe during ongoing vaccine campaigns

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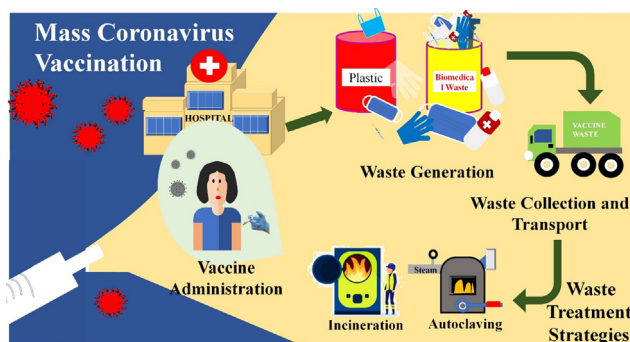
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HIGHLIGHTS

- Surge in vaccine waste is observed during mass vaccination campaigns.
- Marine pollution and CO₂ gas emission are major global disruptions.
- Incineration, autoclaving, chemical disinfection for vaccine waste treatment.
- Substitution of vaccine tools by biodegradable polymers are promising

GRAPHICAL ABSTRACT



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ABSTRACT

The vaccine innovation is a ubiquitous preventive measure to the transmission of highly infectious SARS-COV-2. The ongoing mass coronavirus vaccination programmes have inadvertently become the bulk producers of bio-medical and plastic waste triggering severe impact on the environment. The sustainable management of bio hazardous vaccine waste in particular; syringes, needles, used/un-used vials and single-use plastic equipment is of utmost importance. This perspective presents a critical point of view in terms of the generated vaccine waste and the subsequent knock-on effect on all aspects of ecosystem. The discussion includes dire consequences due to the release of huge amount of plastic-based personal protective equipment into marine environment. The pivotal crisis of CO₂ emission during the manufacture and storage of different vaccines has contributed to global warming. The unavoidable generation of microfibers upon incineration, autoclaving, pyrolysis and open dumping of vaccine waste has further jeopardized the environment. In this vein, exploration of biodegradable materials for vaccine inoculation and development of green technologies for sound waste management is suggested to mitigate the environment pollution.

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1. Introduction

Worldwide health is threatened by the severe acute respiratory syndrome coronavirus-2 (SARS-COV-2) since December 2019. The COVID-19 pandemic has surpassed a death toll of 4 million as of mid-July

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2021, reported by the World Health Organization (WHO) (WHO, 2021a). In the context of grappling pandemic situation, scientific community has successfully navigated through the exploration of antivirals to innovation of vaccines for combatting COVID-19. The intensifying number of reported COVID-19 cases witnessed a decline in January 2021, upon the vaccine administration to age groups at higher fatality risk (Sharma et al., 2021). The current phase of pandemic stage-II is prioritising the bulk manufacturing of vaccines for rapid immunization of large population to defeat the upcoming consequences. The WHO regulatory authorized vaccines are Pfizer/BioNtech, SII/Covishield, AstraZeneca, Janssen/Ad26.COVID2, mRNA/Moderna, Covaxin, Sinopharm, and Sinovac-CoronaVac against COVID-19 variants (WHO, 2021b).

Besides, vaccine being the survival route to COVID-19, the saddle point is the unruly release of COVID-19 vaccine contaminated wastes in the environment. The critical components of COVID-19 pandemic during and after vaccination are completely reliant on plastics including face masks (N95 or other equivalents), personal protective equipment (PPE) kits, gloves, head cover, syringes and other medical gear which are consumed by both healthcare providers and patients (Klemeš et al., 2021). Consequently, exacerbated communal response of massive biomedical waste generation has exposed the vulnerability of global ecosystem demanding for sound waste management. Indeed, an overwhelming avalanche of information is available on the management of COVID-19 waste in the course of pandemic period (Behera, 2021). However, an evident assessment of waste generation during the vaccination era, remains unfolded. This study aims to address the global impact of COVID-19 vaccine waste on the environment, their critical management and safe disposal which would definitely curb the further disease transmission.

2. Assessment of mass vaccination campaigns

The WHO has convened vaccination a mass immunization process to not only prevent the COVID-19 spread but also for the restoration of socio-economic activities. Considering the huge worldwide population, an estimation of bulk vaccine production of nearly 1×10^{10} vaccine

doses of COVID-19 would be accomplished for 1/3 of the world's population by the end of 2021 (Mathieu et al., 2021). India initiated the World's largest vaccination drive in mid-January 2021 with 3000 vaccination centers offering either Covishield or Covaxin dose in a phased sequence by classifying into age group priority. To date, 213 countries have implemented the mass vaccination programme where about 29.5% world population has been administered with 3.58 billion first dose of COVID-19 vaccine as per the logistic database. In disparity, only 1% of the individuals in low-income countries are injected with first dose of vaccine (WHO, 2021c).

The global distribution of vaccines is determined by their efficacy and production rate. So far, the most widely used vaccines are Pfizer BioNtech and mRNA deployed by 61 and 27 countries, respectively claiming nearly 95% efficacy (Mesa-Vieira et al., 2021). "Vaccine against COVID-19" is undoubtedly the most prioritized initiative in the world today perhaps the delay in vaccine procurement for massive amount of population coverage and inequitable distribution is suggestive of poor vaccines availability. In the race to end pandemic, the vaccine rolls out statistics [Fig. 1] worldwide shows 5 billion of COVID-19 administered vaccine doses to fully vaccinate 2.5 billion of the world population as of September 7, 2021 (Ritchie et al., 2020). On the basis of current pace of vaccination drive, the goal of global immunity against COVID-19 is still underway with consequent bulk generation of vaccine waste along the vaccination life cycle. For vaccines that require multiple doses, each individual dose is counted, as the same person may receive more than one dose, the number of doses can be higher than the number of people in the population. Thereby, the estimated number of vaccine doses is 11 billion to immunize the remaining 5.2 billion of world population. The reported increase in vaccine waste is intensifying at a rate of 0.3 to 30% during the vaccination campaigns (Schiffing and Breen, 2021). Perhaps there are different estimations of emergent requirements of vaccines, Crommelin et al. assessed that $5-10 \times 10^9$ vaccine units are required for global distribution (Crommelin et al., 2021). Overall, COVID-19 mass vaccination campaigns clearly underscore the need to optimize and accelerate the

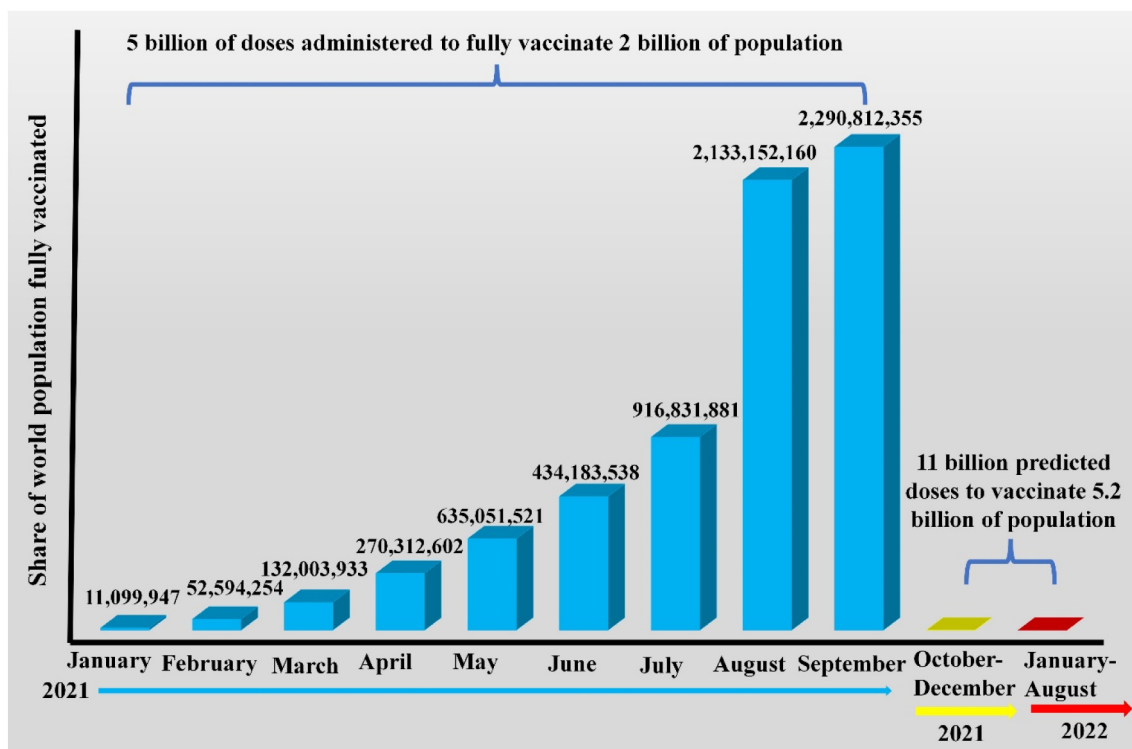


Fig. 1. Graphical representation of the vaccinated population with two doses of vaccine and a predicted time span to immunize the world population with an estimated number of vaccine doses. The data in the graph is used from the information available in <https://ourworldindata.org/coronavirus>.

vaccine multidisciplinary aspects including manufacturing, fair allocation and administration.

3. Waste generated during coronavirus vaccinations

The highly contagious outbreak of COVID-19 pandemic has caused an impending surge in the biomedical waste volumes. At the current pandemic stage II, the environment is facing distress due to the enormous generation of COVID-19 vaccine waste [Fig. 2]. The resources for vaccine manufacture and administration are posing the paramount hardest-hit areas of waste in the countries offering vaccinations. The COVID-19 vaccine waste can be categorised as follows;

- (i) Non-biodegradable plastic waste such as disinfectant bottles, single-use plastics equipment, and vaccine packaging materials have become the polluters of environment. The requirement for disinfectants has remarkably increased as the major transmission of coronavirus is through contact with fomites. The calculated amount of disinfectant needed is 10 L/d for sanitation of 1000 people/dose in a vaccination centre. An unceasing increase in the plastic PPE kits, gloves, face masks, rubber residues, etc. are anticipated waste during the immunization campaigns (Segal, 2021).
- (ii) Consumable waste including syringes, needles, and empty vials are the essential resources of vaccination. Syringes are the major component of vaccine application, which are usually prepared from polypropylene, glass or stainless steel. A standard of massive 3 mL syringe with a low-dead volume are being procured for the exact dosage of vaccine. According to standard operating protocols, syringes are discarded as the cost of manufacture is more economical than recycling which accounts for waste (WHO, 2019).
- (iii) Vaccine wastage is an expected issue of the mass inoculation drive which ultimately increases volumes of biomedical waste. Vaccine wastage can be broadly divided into opened, unopened, and

partially used vials. Typically, the opened and partially used vials (residual dose) are the source of pathogenic vaccine waste. The expected reasons for wastage are unable to draw the desired number of doses, submergence of opened vials in the stored water, and packaging contamination. It is observed that overfilling of vials is a common practice during vaccine application. For instance, the Pfizer vials are designed for five doses (0.3 mL) but in fact it contains 2.25 mL of vaccine which amounts to the partially used vaccine (Mak et al., 2021).

- (iv) Dry ice for storage of vials. The demand for dry ice has increased enormously as all of the globally accepted COVID-19 vaccines are temperature sensitive and requires bulk amount of dry ice for storage at frozen (-18°C) or lyophilic temperature of $2-8^{\circ}\text{C}$. The discarded dry ice is considered as one of the contaminated vaccine wastes (COVID and Team, 2021).

The COVID-19 vaccine waste has pushed the world into dilemma of enduring the immunization against SARS-COV-2 while simultaneously polluting the environment.

4. Effects of COVID-19 vaccine waste on the environment

The prime objective of the mass vaccination strategy is to exit the emergency situation of COVID-19. However, as the vaccination approach is implemented there are intense knock-on-effects on the environment. Presently, the instigating research area is emphasised on the assessment of negative impact on the environment due to vaccination waste. The types of vaccine waste as briefed in above section has caused several disruptions in the environment. The massive bio-waste of discarded vials (fully or partially used) contains thimerosal-mercury based preservative which is hazardous to aqueous ecology and humans when released haphazardly in water bodies. The bulk production and consumption of PPE as a preventive measure to COVID-19 have added

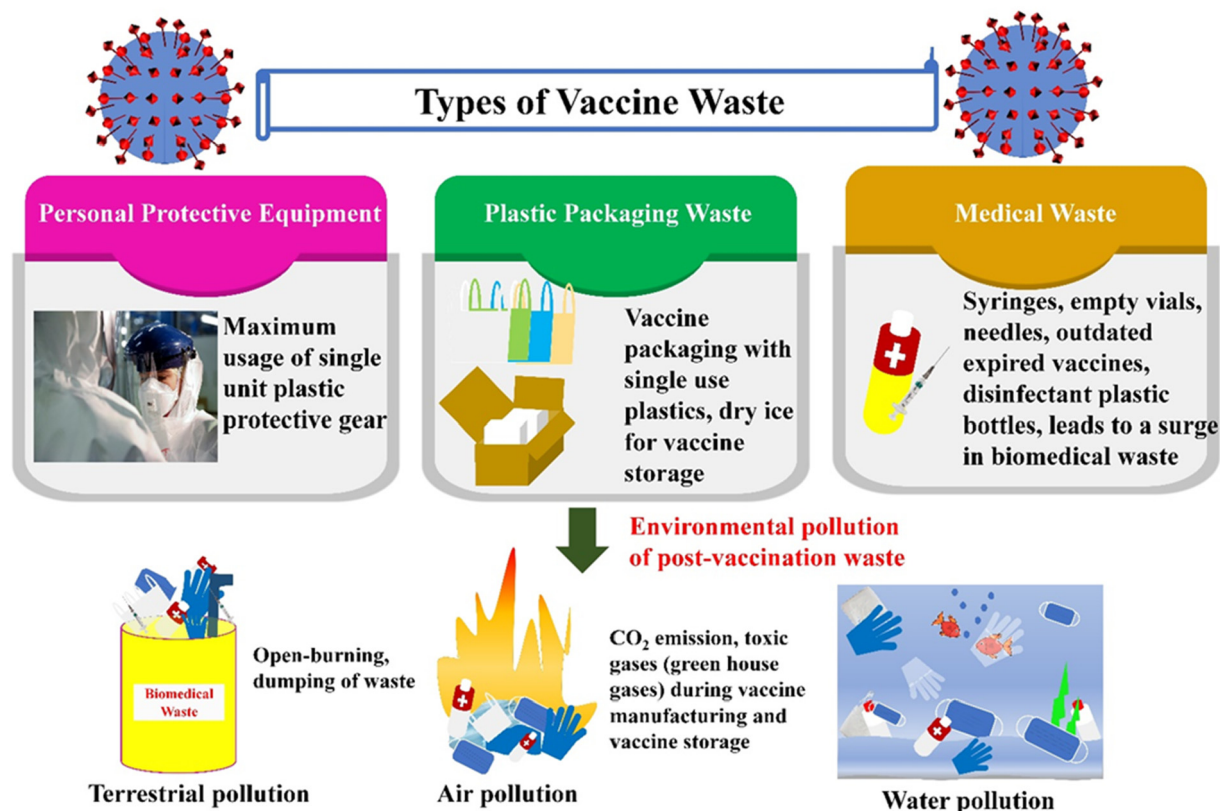


Fig. 2. The types of waste generated from mass COVID-19 vaccination. Adapted with license number CC BY 2.0.

to the microplastic fibers in the environment (Abbasi et al., 2020; Fadare and Okoffo, 2020). This was evident from the investigation of PPE along the coastline of Bushehr port, where the estimated disposal of PPE is 350 per day which are a potential source of secondary microplastics endangering human health and marine environment (Akhbarizadeh et al., 2021). A similar scenario was reported by Ocean Asia, a marine organization which reported presence of 1.56 billion discarded surgical masks in an ocean in Hong Kong, resulting in 4680 to 6240 metric tons of marine plastic pollution which would take 450 years to degrade. An artificial aging experiment was performed on dumped surgical facemask by Saliu et al. where the results indicated 173,000 microfibrils are released per day from the degraded single facemask (Saliu et al., 2021). Even worse, the polypropylene used for N-95 face masks and Tyvek for protective suits, gloves and face shields are persistent in nature and releases dioxins, vinyl chloride in water. An additional implication of plastic-waste was monitored experimentally on contaminated PPE where the ability to sustain the SARS-COV-2 was upto 21 days in the soil load (Kasloff et al., 2021). The slumping of both terrestrial and aquatic environment is mainly due to the novel emergence of face masks and plastic gear as litter which has augmented the levels of plastic pollution (Babaahmadi et al., 2021).

The ecological imbalance due to the load of packaging, storage and deep-freezing of vaccines have imposed a significant increase in the CO₂ greenhouse gas (Phadke et al., 2021; Kumar et al., 2021). Kurzweil et al. explored a case study of carbon footprint in Germany and reported a total of 0.01 to 0.2 kg of CO₂ equivalents upon per dose of mRNA vaccine injection. Until now one million doses of two mRNA vaccines have been injected in Germany and has emitted 1100 kg CO₂, due to the different freezing temperatures of vaccines and their cold supply chain

(Kurzweil et al., 2021). The global warming impact due to refrigeration of COVID-19 vaccines was indicated by total equivalent warming impact index values. From the analysis, it was concluded that cold storage of Pfizer vaccines generated 35-times more CO₂ emission than AstraZeneca, Janseen/Ad26.CO2, and Corona Vac vaccines (Santos et al., 2021). It is clearly assessed that after the contagion risk of pandemic, the second alarming crosscurrent is the accumulation risk of dire climate hazards. Hence, the present scenario of declining ecology demands for imperious vaccine waste management organizations to combat the established succession of threat on various aspects of environment [Fig. 3].

5. Conclusions and future outlook

The critical management of COVID-19 vaccine waste has become a global challenge to impede the back-firing impact on the environment and human health. This review provides an overview on the COVID-19 vaccine waste and unforeseen impact on every aspect of environment. The study assesses the waste generated during vaccination campaigns based on the share of population vaccinated. Different types of vaccine waste including; protective equipment, needles, syringes, vaccine vials, and dry ice for vaccine storage, etc. are comprehensively discussed along with the prevailing environment impact. Typically, the effective vaccine waste management includes segregation of biomedical waste from other plastic waste which is discarded at the campaigns followed by disinfection and targeted disposal techniques. Based on the current waste management routes, various possible sustainable alternatives such as bio-plastics, microneedles, and other biological materials have been proposed. Since, the vaccine manufacture and pace of

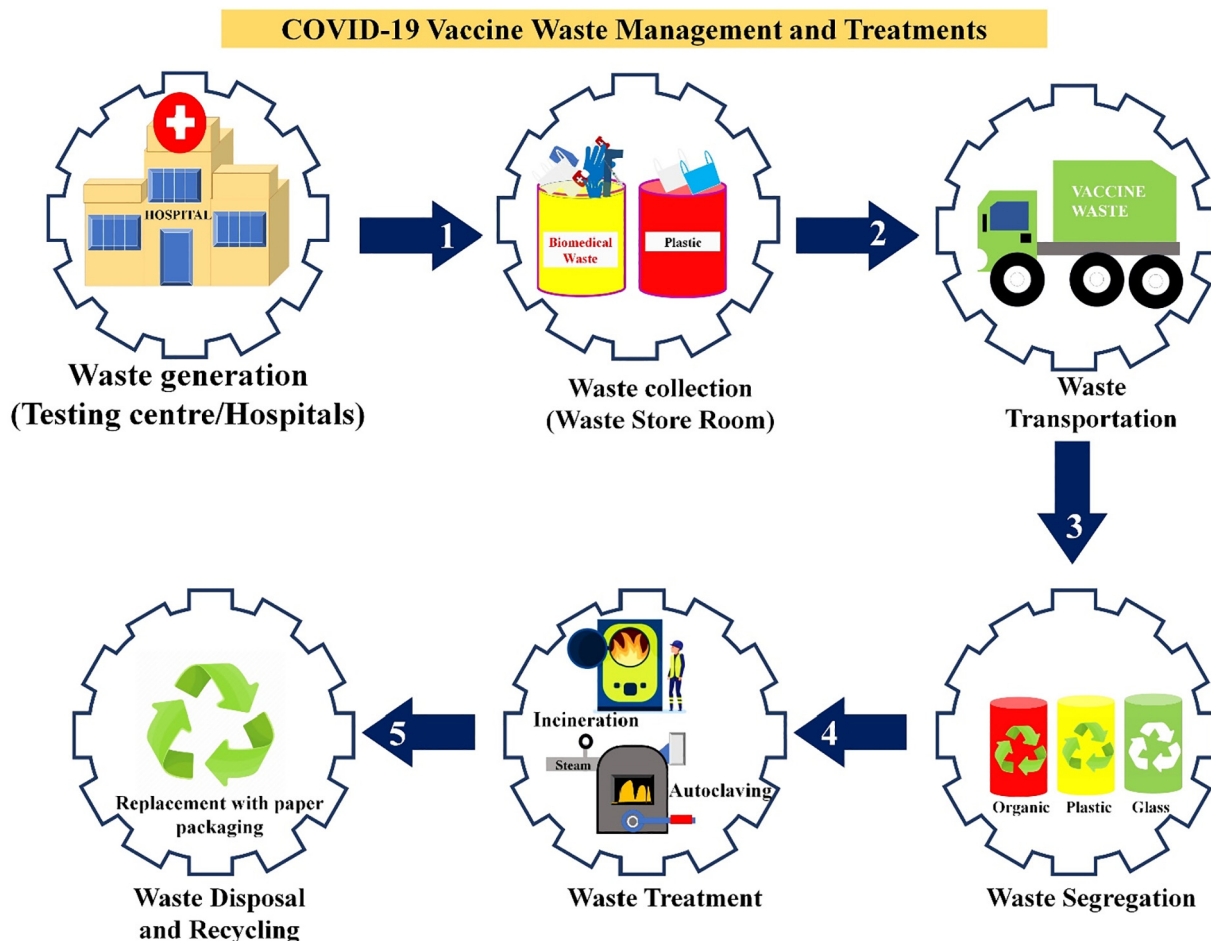


Fig. 3. Schematic illustration of COVID-19 vaccine waste management and treatments.

immunization process are likely to drastically increase. It is anticipated that the community cooperation to abide by the existing protocols for waste management is the key factor to combat the further transmission of COVID-19 disease. Moreover, large scale initiative of integrating novel sustainable technologies into current waste management system would foresee either recycling or reusing of plastic based vaccine tools for on-going vaccination programmes. The future research is suggested for innovation of specialized vaccines to overcome the drawbacks of mRNA technologies and cold-chain storage which would lessen the amount of greenhouse gas emission.

CRedit authorship contribution statement

All authors participated equally.

Declaration of competing interest

All Authors declare no conflict interest.

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